International Journal of Electrical and Electronics Engineering Research (IJEEER)
ISSN(P): 2250-155X; ISSN(E): 2278-943X
Vol. 4, Issue 1, Feb 2014, 105-112

A NOVEL SWITCHING PATTERN CONTROL FOR SENSOR AND SENSOR LESS BASED FOUR SWITCH INVERTER FED PMBLDC DRIVE

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ABSTRACT

Brushless DC (BLDC) motor is attracting much interest due to its high efficiency, good performance and ease of control for many applications. Moreover, reducing of the drive components is more attractive for low cost applications. The paper presents a comparative study between sensor and sensor less control of four-switch Inverter fed PMBLDC (BLDC) motor drive which is suitable for low cost application. The conventional techniques for controlling the phase current in a FSTPI brushless DC drive are practically effective in low speed and cannot reduce the commutation torque ripple in high speed range. For effective utilization of the developed system, a novel direct current controlled PWM scheme is designed and implemented to produce the desired dynamic and static speed–torque characteristics. The simulation results are obtained using MATLAB/SIMULINK software.

KEYWORDS: BLDC Motor, Four Switch Inverter

INTRODUCTION

The BLDC motor is a rotating electric motor consisting of three- phase armature windings on the stator and permanent magnets on the rotor. The mechanical structure of BLDC motor is the conventional permanent magnet brushed DC motor (PMDCM) inside out, the rotor contains permanent magnets and the motor windings are mounted on the stator. The BLDC motor does not have any brushes, those required in the commutation of PMDCM. Therefore the maintenance free motor drive system is possible with BLDC motor. The permanent magnets on the rotor of the BLDC motor provide a constant rotor magnetic field and makes possible a highly efficient, high torque-per volume, and low moment of inertia [1]. The BLDC motor is an electronically commutating permanent magnet DC motor. Because of this motor's inherent variable speed drive nature, its applications are growing, in automobile and machine building industries.

Some work has also been done on a sensored four switch BLDC motor drive. An asymmetric PWM scheme for a four-switch three-phase BLDC motor drive to make six commutations and produce four floating phases to detect back electromotive force. The position information of the rotor can be acquired based on the crossing points of the voltage of controllable phases. Virtual Hall sensor signals are made by detecting the zero crossing points of the stator terminal voltages, and there is no need to build a 30◦ phase shift, which is prevalent in most of the sensored algorithms.[7] A four-switch three-phase BLDC motor drive is proposed to simplify the topological structure of the conventional six-switch inverter. The uncontrollable phase current causes unsymmetrical voltage vector and its waveform is much of distortion from rectangular. The direct current control based on hysteresis avoids this problem and it senses currents of phases A and B individually by two current sensors and then switches them separately [1] [2] [4].

DESCRIPTION OF PMBLDCM DRIVE

Figure 1 describes the basic building blocks of the PMBLDCM drive. The drive consists of speed controller,

reference current generator, pulse width modulation (PWM) current controller, position sensor, the motor and a IGBT based voltage source inverter (CC-VSI). The speed of the motor is compared with its reference value and the speed error is processed in PI speed controller. The output of this controller is considered as the reference torque. A limit is put on the speed controller output depending on permissible maximum winding currents. The reference current generator block generates the three phase reference currents (i_a^*, i_b^*, i_c^*) using the limited peak current.

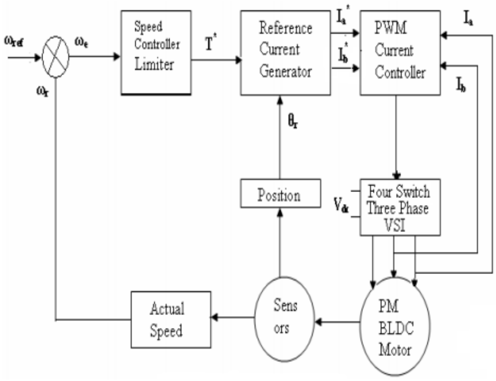

Figure 1: PI-Speed Controller

The PI controller is widely used in industry due to its ease in design and simple structure. The rotor speed $\omega_r(n)$ is compared with the reference speed $\omega_r(n)^*$ and the resulting error is estimated at the nth sampling instant as

$$\omega_e(n) = \omega_r(n)^* - \omega_r(n) \tag{1}$$

The new value of torque reference is given by

$$T(n) = T(n-1) + K_P \omega_e(n) - \omega_e(n-1) + K_I \omega_e(n) \tag{2}$$

Where, '$\omega_e(n-1)$'is the speed error of previous interval, and '$\omega_e(n)$' is the speed error of the working interval. KP and KI are the gains of proportional and integral controllers respectively. By using Ziegler Nichols method the KP and KI values are determined [1].

Reference Current Generator

Unlike a brushed DC motor, the commutation of a BLDC motor is controlled electronically. To rotate the BLDC motor, the stator windings should be energized in a sequence. Most of BLDC motors have three Hall sensors embedded into the stator on the non-driving end of the motor. Rotor position is sensed by Hall Effect sensors embedded into the stator which gives the sequence of phases. Whenever the rotor magnetic poles pass near the Hall sensors, they give a high/low signal, indicating the N or S pole is passing near the sensors. Based on the combination of these three Hall sensor signals, the exact sequence of commutation can be determined. The magnitude of the reference current (I^*) is determined by using reference torque (T^*) and the back emf constant

(Kb); $I^* = \frac{T^*}{K_b}$. Depending on the rotor position, the reference current generator block generates three-phase reference currents (i_a^*, i_b^*, i_c^*) considering the value of reference current magnitude as I^*, $-I^*$ and zero. The reference current generation is shown in Figure 2.

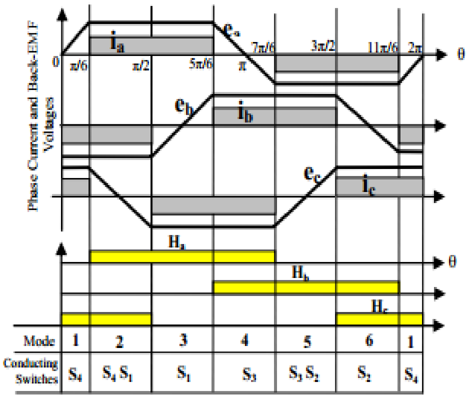

Figure 2: Back EMF, Current Profile, Modes, Conducting Switches in the Four-Switch Converter for Three-Phase BLDC Motor Drives

Terminal voltages of a BLDC motor in the four-switch inverter with respect to the mid-point of the dc bus are as follows:

$$V_{ao} = Ri_a + L\frac{di_a}{dt} + e_a + V_{no} \tag{3}$$

$$V_{bo} = Ri_b + L\frac{di_b}{dt} + e_b + V_{no} \tag{4}$$

$$V_{co} = Ri_c + L\frac{di_c}{dt} + e_c + V_{no} \tag{5}$$

OPERATIONAL PRINCIPLE OF DIRECT CURRENT CONTROLLED PWM

From the motor point of view, even though the BLDC motor is supplied by the four-switch converter, ideal back-EMF of three-phase BLDC motor and the desired current profiles can be described as shown in Figure 2. From the detailed investigation of the four-switch configuration and back-EMF and current profiles, we could come up with a PWM control strategy for the four-switch three-phase BLDC motor drives as follows: Under a balanced condition, the three-phase currents always satisfy the following condition

$$I_a + I_b + I_c = 0 \tag{6}$$

Then, (1) can be modified as

$$\mathbf{I_c = -(I_a + I_b)} \tag{7}$$

In the case of the ac induction motor drive, at any instant there are always three phase currents flowing through the load, such as

$$I_a \neq 0;\ I_b \neq 0;\ I_c \neq 0 \tag{8}$$

However, in the case of the BLDC motor drive, (3) is not valid anymore. Note that in Figure 2 phase A and B currents are only controllable and phase C is uncontrollable. According to the operating modes, one can derive the following current equations: Table 1 implies that due to the characteristics of the BLDC motor, such as two-phase, only two phases (four switches) needed to be controlled, not three phases. Therefore, based on Table 1, one can develop a switching sequence using four switches as follows:

Table 1: Rotor Position Signal vs Reference Current

Rotor Position Signal θ_r	Reference Currents (i_a*, i_b*, i_c*)		
330°-0° to 0°-30°	0	–I*	I*
30° - 90°	I*	–I*	0
90° -150°	I*	0	–I*
150° - 210°	0	I*	–I*
210° - 270°	–I*	I*	0
270° - 330°	–I*	0	I*

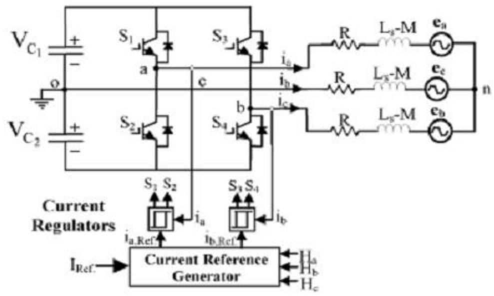

Figure 3: Proposed Four-Switch Converter Topology for Three-Phase BLDC Motor

As shown in Table 2, the two-phase currents need to be directly controlled using the hysteresis current control method by four switches. Hence, it is called the direct current controlled PWM scheme. Based on the direct current controlled PWM, implementation of the switching sequence and current flow are depicted in Figure 6.

Table 2: Switching Sequence of Four Switch BLDC Motor

MODES	ACTIVE PHASES	SILENT PHASES	SWITCHING DEVICES
Mode 1	Phase B and C	Phase A	S_4
Mode 2	Phase A and B	Phase C	S_1 and S_4
Mode 3	Phase A and C	Phase B	S_1
Mode 4	Phase B and C	Phase A	S_3
Mode 5	Phase A and B	Phase C	S_2 and S_3
Mode 6	Phase A and C	Phase B	S_2

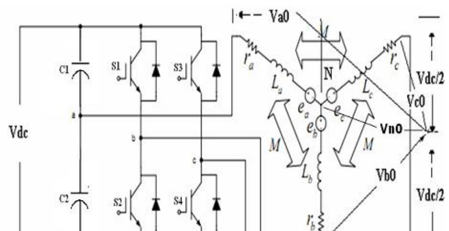

Figure 4: Inverter Circuit with PMBLDCM Drive

FOUR SWITCH CONVERTER TOPOLOGY

The cost reduction of controllers for PMBLM drives can be considered with the topologies with more than one switch per phase, but less than conventional two switches per phase. But according to the working of BLDCM, at a time only two phases are conducing and the third phase is inactive [2-5].A BLDC motor needs quasi-square current waveforms, which are synchronized with the back-EMF to generate constant output torque and have 120 degree conduction and 60 degree non-conducting regions. However, in the four-switch converter, the generation of 120 degree conducting current profiles is inherently difficult Though cost saving is achieved, it introduces distortions in the uncontrolled phase.

This problem is solved by using hysteresis current control. In this method pwm pulses produced by the switching ON and OFF the switch when the phase current crosses the Hysteresis Band.

Closed Loop Operation

The closed loop operation carried out by the voltage controller (PI controller) processes the error signal and produces appropriate current signal (*I*S). The current signal (*I*S) is multiplied with unit sinusoidal template which is produced by using phase locked loop (PLL), to produce *I*S sinωt. The load current *iL* subtracted from the *I*S sin ωt to produce the reference current signal *i*S*. As the boost inductor current can't be alternating, the absolute circuit gives the absolute value of the reference current signal *i*S* that is *iC**. The actual signal (*i*C) and the required reference signal (*iC**) are given to the current controller to produce the proper gating signal. The current controller adopted is a hysteresis current controller. Upper and lower hysteresis band is created by adding and subtracting a band '*h*' with the reference signal *i*C* respectively shown in the Figure 8. The inductor current is forced to fall within the hysteresis band. When the current goes above the upper hysteresis band, i.e. *i*C *+*h*, the pulse is removed resulting the current forced to fall as the current will flow through the load. When the current goes below the lower hysteresis band i.e. *i*C *-*h*, the pulse is given to the switch, so the current increases linearly.

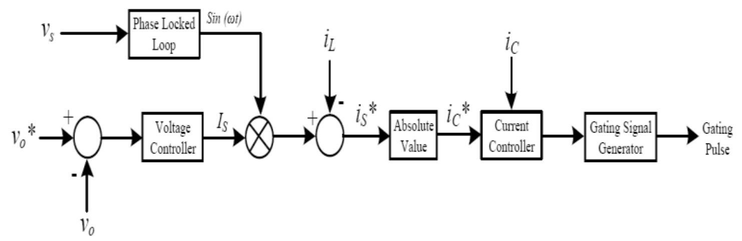

Figure 5: Adopted Control Scheme for the Closed Loop Operation

MATLAB MODELING AND SIMULATION RESULTS

Here simulation is carried out in two different cases, in that 1). Proposed Four Switch Three Phase Inverter Fed BLDC Motor with constant speed condition 2). Proposed Four Switch Three Phase Inverter Fed BLDC Motor with variable speed condition.

Case 1: Proposed Four Switch Three Phase Inverter Fed BLDC Motor with Constant Speed Condition.

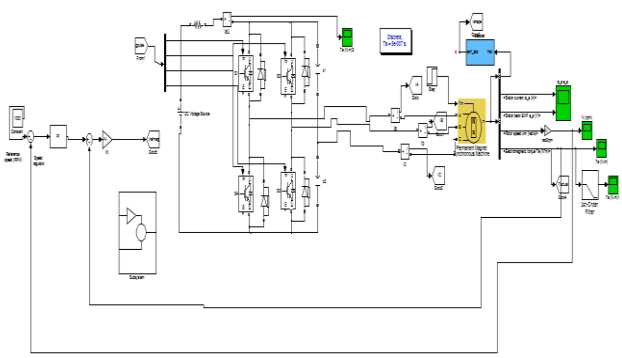

Figure 6: Matlab/Simulink Model of Proposed Four Switch Three Phase Inverter Fed BLDC Motor with Constant Speed

Figure 6 shows the Matlab/Simulink Model of Proposed Four Switch Three Phase Inverter Fed BLDC Motor with constant speed condition using Matlab/Simulink Platform.

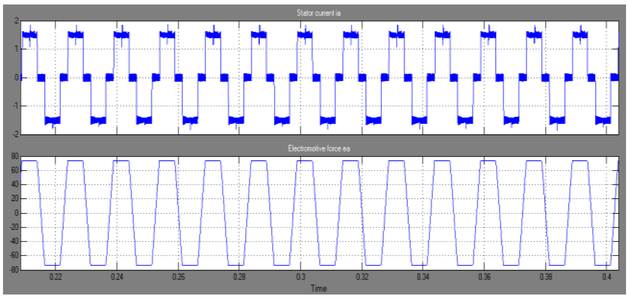

Figure 7: Stator Current & Back EMF

Figure 7 shows the Stator Current & Back EMF of Proposed Four Switch Three Phase Inverter Fed BLDC Motor with constant speed condition.

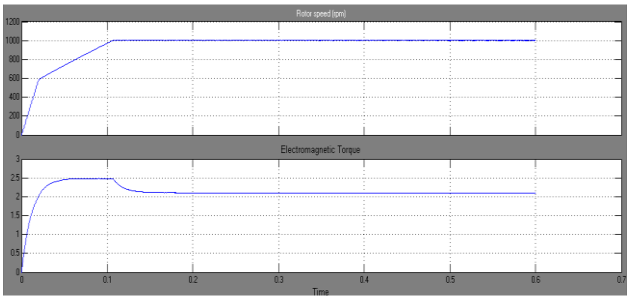

Figure 8: Speed & Electromagnetic Torque

Figure 8 shows the Speed & Electromagnetic Torque of Proposed Four Switch Three Phase Inverter Fed BLDC Motor with constant speed condition

Case 2: Proposed Four Switch Three Phase Inverter Fed BLDC Motor with Constant Speed Condition

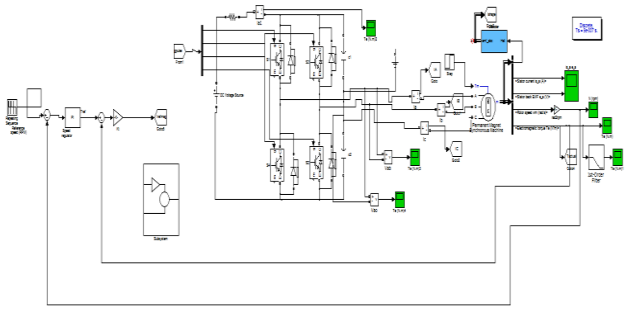

Figure 9: Matlab/Simulink Model of Proposed Four Switch Three Phase Inverter Fed BLDC Motor with Variable Speed

Figure 9 shows the Matlab/Simulink Model of Proposed Four Switch Three Phase Inverter Fed BLDC Motor with variable speed condition using Matlab/Simulink Platform

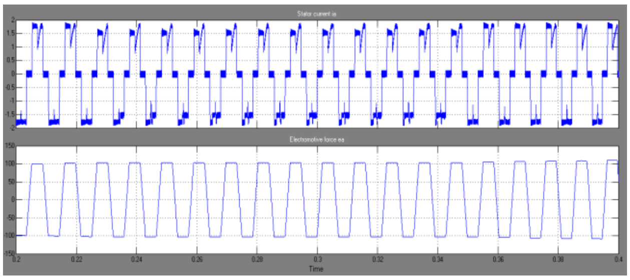

Figure 10: Stator Current & Back EMF

Figure 10 shows the Stator Current & Back EMF of Proposed Four Switch Three Phase Inverter Fed BLDC Motor with variable speed condition.

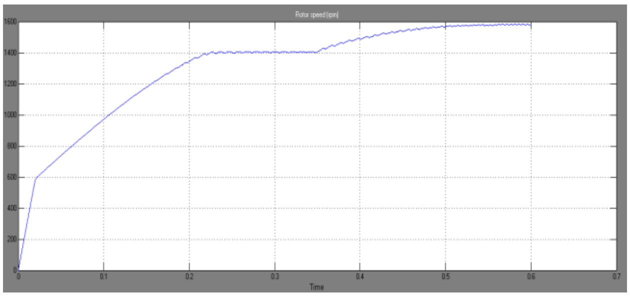

Figure 11: Speed

Figure 11 shows the Speed of Proposed Four Switch Three Phase Inverter Fed BLDC Motor with variable speed condition.

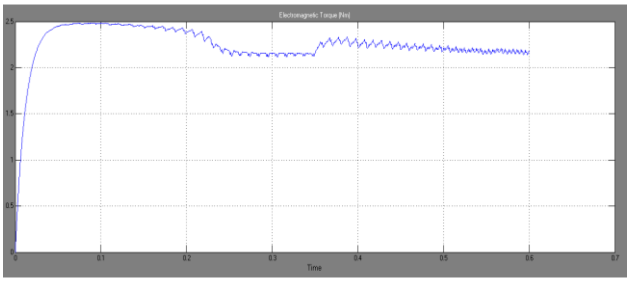

Figure 12: Electromagnetic Torque

Figure 8 shows the Electromagnetic Torque of Proposed Four Switch Three Phase Inverter Fed BLDC Motor with variable speed condition.

CONCLUSIONS

Classical PI controller is most popular controller and widely used in most power electronic closed loop appliances however recently there are many researchers reported successfully adopted to their appliances. With respect to their successful methodology implementation, control closed loop converter and opened loop converter will compare the efficiency of the converters.The simulation model of the BLDC motors drive system with PI control based four switch three phase inverter with constant & variable speed condition is evaluated using MATLAB/Simulink platform is presented. The performance of the developed algorithm based speed controller of the drive has revealed that the algorithm devises the behaviour of the PMBLDC motor drive system work satisfactorily. And also the four-switch inverter topology is studied using pi controller based constant & variable speed loop control to provide a possibility for the realization of low cost and high performance three-phase BLDC motor drive system.

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